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Electrical system simulation of an aircraft through ANSYS Electronics Desktop

Simulación del sistema eléctrico de una aeronave a través de ANSYS Electronics Desktop

REGALADO-RANGEL, Karina†*, GASTELLUM-MICHEL, Filiberto, TORRES-RIVERA, Moisés and TRASLOSHEROS-MICHEL, Alberto

Universidad Aeronáutica en Querétaro

ID 1st Author: *Karina, Regalado-Rangel* / **ORC ID**: 0000-0002-4497-665X

ID 1st Co-author: *Filiberto, Gastellum-Michel* / **ORC ID**: 0000-0001-7578-0257

ID 2nd Co-author: *Moisés, Torres-Rivera* / **ORC ID**: 0000-0001-6668-2903, **CVU CONACYT ID**: 634138

ID 3rd Co-author: *Alberto, Traslosheros-Michel* / **ORC ID**: 0000-0002-9857-7777, **CVU CONACYT ID**: 103311

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Abstract

More Electric Aircraft is a new technology that allows the aeronautical sector to innovate in the electrical part when it comes to implementing it, that is, it consists of replacing part of the current pneumatic, hydraulic and mechanical systems that make up an aircraft, with electrical systems, for this reason, the main purpose is to design and develop a simulation model in ANSYS Electronics Desktop of the Boeing 777 architecture to analyze all the parameters such as: the voltage, current and power of each subsystem, so for the development, they are simulated one by one and later, they are joined based on the electrical diagram of the aircraft in order to be able to test them in normal and abnormal conditions, and make the comparison of when they are simulated individually, in this way, it creates an impact when rebuilding the electrical system, generating advantages that benefit those companies in this sector for the contribution of their innovations.

Power Electronics, Aircraft, Simulation

Resumen

More Electric Aircraft es una nueva tecnología que permite al sector aeronáutico innovar la parte eléctrica cuando esta se implementa, es decir, esta consiste en reemplazar parte de los sistemas neumáticos, hidráulicos y mecánicos actuales que conforman una aeronave, por sistemas eléctricos, por ello es que el propósito principal es diseñar y desarrollar un modelo de simulación en ANSYS Electronics Desktop de la arquitectura del Boeing 777 para analizar todos los parámetros como: el voltaje, corriente y potencia de cada subsistema, por lo que para el desarrollo, se simula uno por uno y posteriormente, se unen con base en el diagrama eléctrico de la aeronave con el fin de poder probarlos en condiciones normales y anormales, y realizar la comparación de cuando se simulan de manera individual, por lo que crea un impacto al reconstruir el sistema eléctrico, generando ventajas que beneficia a aquellas empresas de este sector para la contribución de sus innovaciones.

Electrónica De Potencia, Aeronaves, Simulación

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*Correspondence to Author (e-mail: 5689@soyunaq.mx)
†Researcher contributing as first Author.

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Introduction

The aeronautical industry and the development of simulations have been evolving over time, because those platforms that serve as a tool to perform simulations, help to have a better overview of specific tests which benefits a large number of users, as this allows them to modify the simulation as many times as necessary and at the same time check results to achieve the desired goal, and avoid costs when it is done in a physical way.

On the other hand, since the beginning of aircraft development, general problems have been solved and the electrical system has been innovated: in question of the generators, at the beginning there were direct current generators, and provided on average 250 W at 6 V or 500 W at 12 V by the year 1936, and later, in the year 1950, this was able to provide 1 kW at 28 V and soon after it was possible to obtain a power of 18 kW, however, However, this power level had limitations at significant heights so that several generators of this type had to be connected in parallel causing converters and bulky batteries, and the properties of the insulators were not sufficient, which is why they began to implement alternating current generators in order to solve those drawbacks of direct current generators.

This type of generators have advantages such as being able to provide higher power levels and are lightweight by reducing the number of cables by having a voltage of 120 VAC, and the voltage change can be done more easily thanks to the use of transformers, despite this, it has disadvantages such as its frequency instability so additional units are needed to control it as is the Constant Speed Driver or hydromechanical systems that have evolved over time, and this is where More Electric Aircraft (MEA) enters (Arabul, *et al*., 2021).

MEA is a technology focused on power generation, i.e., its conversion and distribution. MEA does this by eliminating part of the pneumatic, hydraulic and mechanical systems by electrical systems, i.e., when part of the pneumatic system is eliminated, it has an engine without bleeding.

So that in this way fuel consumption is reduced, when talking about the other two mechanical and hydraulic systems, they reduce installation and operating costs as they are less complex systems, so that in general, there are advantages such as: having a simple monitoring of the components and less time for maintenance, prediction of the useful life of the aircraft, advanced prognostics and diagnostics, as well as an important feature which is the reduction of air pollution.

Now, making relevance to one of the main features is that, in this, the use of relays or contactors are replaced by MOSFET or IGBT type transistors for load control, either in DC or AC which impacts on power generation, which is why the electrical system of the Boeing 777 is simulated which compared to the Boeing 787, This is done with the purpose of being able to analyze its parameters and from this, begin to make modifications for the innovation of this aircraft, and in turn, this simulation serves as a basis for any other type of commercial aircraft.

Next, an example of the difference between a conventional aircraft and an aircraft with MEA is presented, in Figure 1, it can be seen that several functions are carried out thanks to the air bleed, compared to Figure 2, these functions are replaced to do it electrically, leaving only the anti-icing system that performs the pneumatic system with the air bleed.

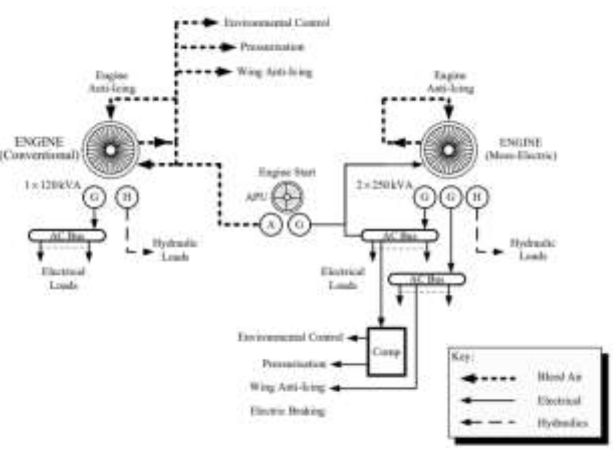

Figure 1 Electrical system of a conventional aircraft (Moir & Seabridge, 2011)

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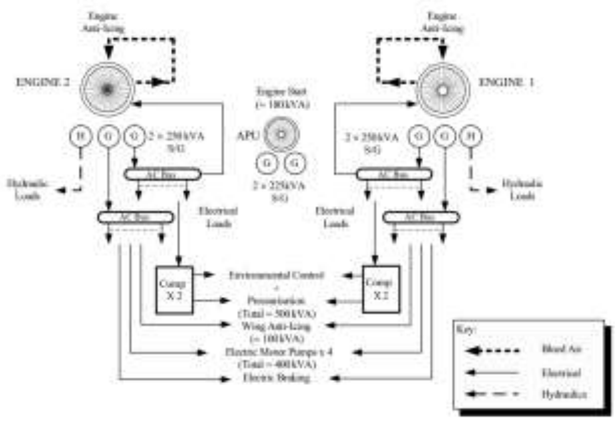

Figure 2 Boeing 787 aircraft electrical system with MEA (Moir & Seabridge, 2011)

Through this pair of examples, it can be seen that thanks to MEA technology, it is possible to replace part of the pneumatic systems that generate the air bleed, and hydraulic systems, by electrical form, in order to modify the architecture of the complete system of the aircraft and obtain benefits such as having more power thanks to the generators (Wheeler & Bozhko, 2014).

All the changes observed were achieved with an extensive study, simulation and testing of the same, and this is where the importance of the simulation of the aircraft systems comes in (Faruque, 2015) (Zhangang, Junchao, Yingchuan, & Xudong, 2015), since in this way, allows you to perform different types of tests according to the needs you have, and in this case, by doing it through ANSYS Electronics Desktop, all its results are validated by the Federal Aviation Administration (FAA), therefore, those tests that are performed, may be implemented in real applications.

The following sections are presented in this article, in which, first is a brief theory about each of the subsystems that are simulated, then, the simulation of them, and finally, the simulation of the complete electrical system and its results respectively.

Aircraft electrical subsystems

Integrated Drive Generator

It is one of the main sources that make up the electrical system of the aircraft, they work under normal conditions and there is one on each side, that is, on the left side and on the right side.

The architecture of this consists of four main parts, which are: *the turbine*, which generates mechanical power and this is extracted through a shaft which is then distributed in a gearbox, which is responsible for converting this mechanical power into variable speed, so that it then enters the *Constant Speed Driver* and converts this variable speed by constant speed to generate the rpm necessary to obtain the 400 Hz and thus the *generator* with the help of the *General Control Unit* can turn on and feed the corresponding subsystems.

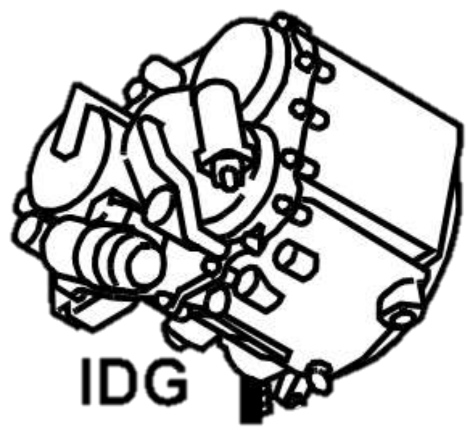

Figura 3 Integrated Drive Generator

Transformer Rectifier Unit

It is considered as the main converter of the electrical system, since it converts from alternating current (AC) to direct current (DC), that is, this unit consists of a three-phase transformer with star-delta arrangement, which receives 115 VAC and after the transformer acting as a step-down type, enters a three-phase bridge rectifier to obtain at the output a voltage of 28 VDC with the help of capacitors and resistors that act as a filter and current control.

Main Battery

As is known, a battery is one that is capable of converting chemical energy into electrical energy, and in an electrical system, it is one of the secondary sources. In general, within the aeronautical sector there are three types of batteries: nickel-cadmium, lithium-ion and lead-acid, each with different characteristics, however, in the Boeing 777 the nickel-cadmium type is used, due to the advantages it has over the others, for example, that it maintains a constant voltage when discharged at high current levels, and also has a balanced ratio between capacity and weight.

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They are usually found near the busbars in special trays to avoid the use of long cables and if at any time there is a leakage of any chemical, they remain in the trays and do not affect other components. Regarding its functions, the battery helps to supply power in the short term when the IDG or the Auxiliary Power Unit are not available, likewise, in emergency conditions, it supplies power to the flight instruments essential for maneuvering the aircraft, radio communication equipment, etc.

Figure 4 Representation of an aircraft battery

Main Battery Charger

Due to the limited capacity of the battery, there is a charger designed for it, so that, depending on the battery conditions used, the charger will be able to control the battery contactors for connecting and disconnecting the busbars during charging and discharging. This charger is 24 V, 15 kVA and has a power factor of 0.95.

Flight Control Direct Current

It refers to the flight instruments that are responsible for maneuvering the aircraft, so it is a subsystem that needs redundancy in its power supply, so it can be fed from the CD transfer bar, the battery or the output of the Permanent Magnet Generator.

Subsystem Simulations in ANSYS Electronics Desktop

Integrated Drive Generator

The simulation is presented below, where the output is 115 VAC and a current of approximately 900 A.

This simulation consists of the 4 stages previously mentioned, the turbine, where after it is the gearbox that enters directly to the Constant Speed Driver, and then the generator, which as seen, is connected to a unit (GCU), which is essential, since it serves as voltage, frequency and current control, as well as protection for the generator, and finally, there are three electrical resistors, for the three-phase output of this generator.

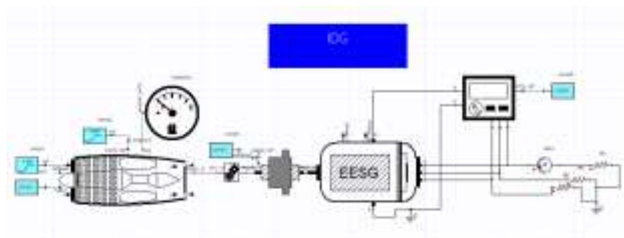

Figure 5 GDI simulation

Transformer Rectifier Unit

For this part, at the input we receive 115 VAC three-phase through the transformer, which as mentioned above, will act as a step-down with star-delta arrangement and as can be seen, then we have the bridge rectifier to obtain direct current of approximately between 250 and 300 A with 28 V.

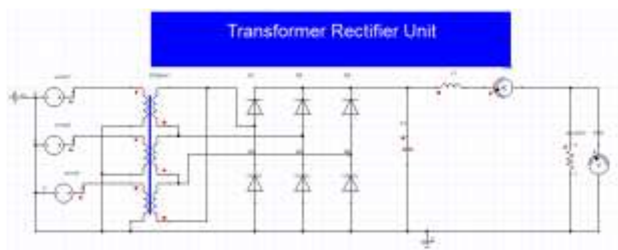

Figure 6 TRU simulation

Main Battery/ Main Battery Charger

The main battery and its charger are simulated as follows, i.e., with the help of a switch, it can be decided whether the battery is powered or charged through the switch. For the battery part, it consists of two parts, which is the battery with a current source that the battery will be able to supply, and for the charger part it consists of two parts, the three-phase step-down transformer and the three-phase bridge rectifier, in order to obtain direct current and thus can charge the battery.

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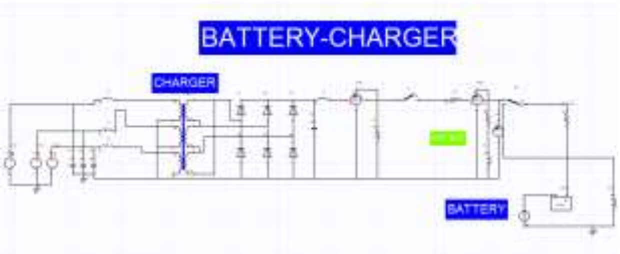

Figura 7 Simulación de Main Battery/ Main Battery Charger

Flight Control Direct Current

Being the representative subsystem for the flight controls, i.e. those that manage the control surfaces, this is simulated by means of resistors, however, as mentioned before, it is a subsystem that needs redundancy, so it will have three possible power supplies available.

Simulations of the complete electrical system

Power flow diagram

In order to make the connection between each subsystem, it was based on the following diagram obtained from Boeing 777 Electrical System: *Wings of America Training Center* Training Manual, in which you can see the power flow on both sides, in order to identify in which part is the AC power and DC, and thus, the analysis can be performed under normal conditions, ie, when the system is operating normally.

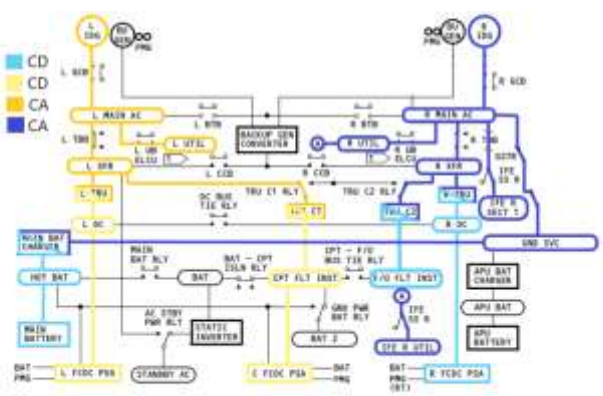

Figure 8 Power flow diagram of the Boeing 777 electrical system

From the above, we proceed to join each subsystem in order to subsequently obtain the results and compare them when the subsystem works individually.

Left Side

Based on the previous diagram, the subsystems corresponding to the left side are joined and the corresponding connections are made to the busbars shown in the diagram.

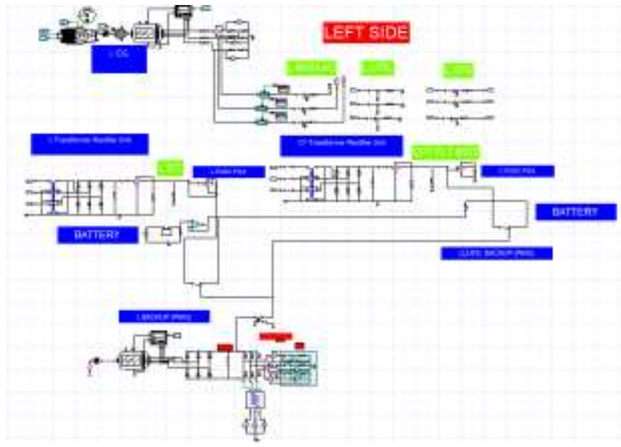

Figure 9 Simulation corresponding to the left side of the electrical system

It starts from its main source, which is the IDG, and from there, the left AC main bus is connected so that, from it, power can be supplied to the other buses and to both TRUs so that they can perform their function properly.

Right Side

For the case of the right side, the same thing happens, in which the subsystems are joined and the busbars are added along with switches to be able to control the current flow in them, again starting from the IDG power supply that goes to the right AC main busbar and thus, through labels, connections can be made between each bus and each subsystem to be able to feed them.

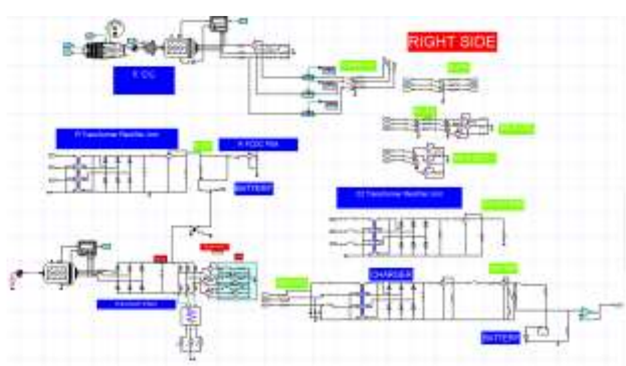

Figure 10 Simulation corresponding to the right side of the electrical system

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Simulation results by subsystems

For this section, the most representative graphs of each subsystem are presented with the purpose of verifying that the parameters mentioned in the Subsystems section correspond with the output of each one of them already in simulation, that is to say that they have the same behavior both individually and as a whole.

Integrated Drive Generator

For this subsystem, in the following Figures, it can be seen that the voltage is 162.63 V which corresponds to 115 VRMS with a current of approximately 900 A.

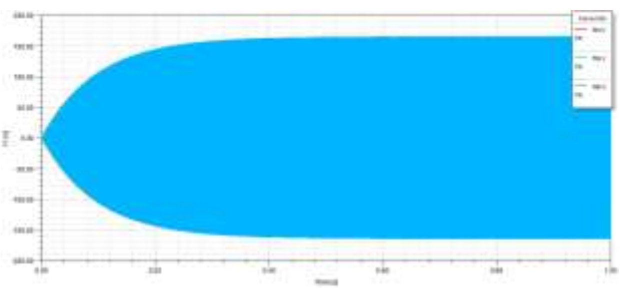

Figure 11 IDG voltage output during a simulation period of 1 second

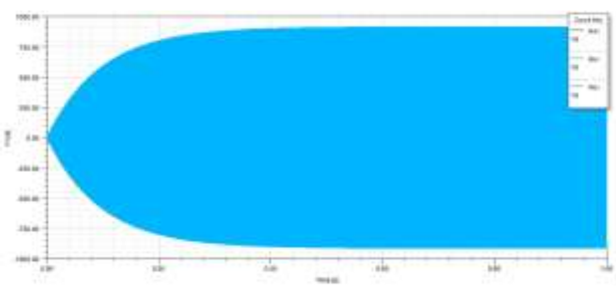

Figure 12 IDG current output during a simulation period of 1 second

Transformer Rectifier Unit

The voltage output of this subsystem is 28 V as can be seen and remains constant.

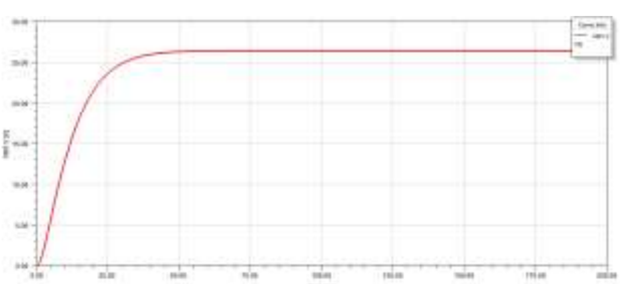

Figure 13 TRU voltage output

For the current case, it is very close to 250 A, so it falls within the current range mentioned above.

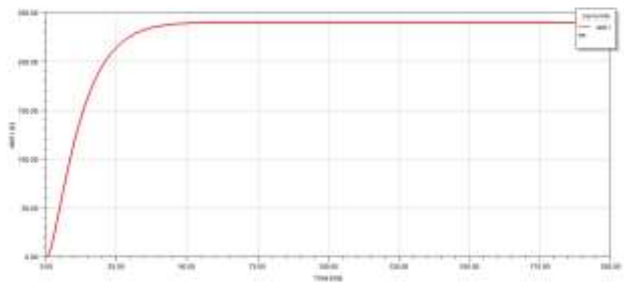

Figure 14 Current output of the TRU

Main Battery

For the battery case, it is 23.75 V with 25 A current.

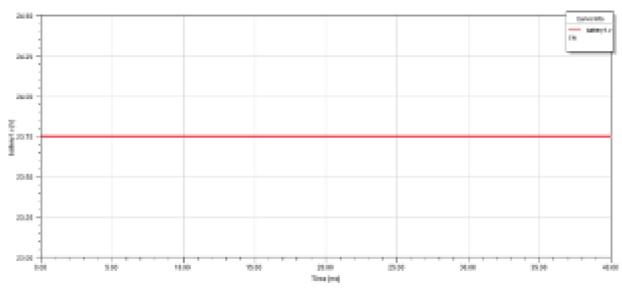

Figure 15 Battery voltage output

Main Battery Charger

In this section we have 24 V output with a current of 600 A as shown in the following result.

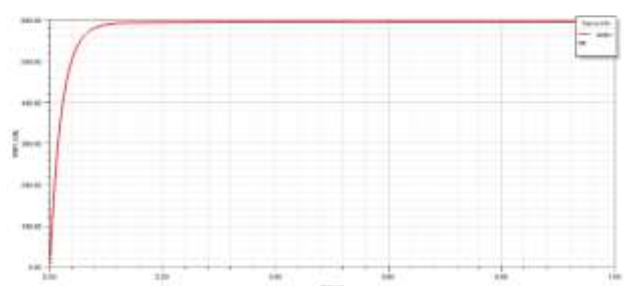

Figure 16 Battery charger current output

Having a voltage of 24 V and a current as mentioned, the power is approximately 14.25 kW considering the power factor of 0.95.

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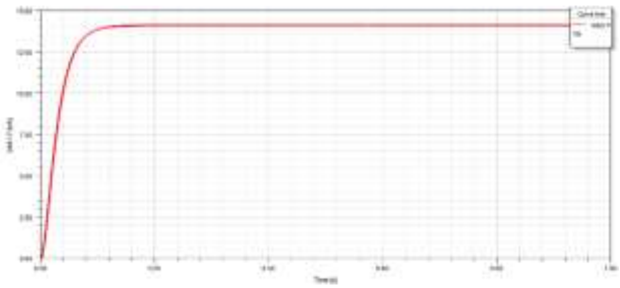

Figure 17 Resulting power output from the battery charger

Simulation results of the complete electrical system

After the above, the results are divided into two sides, and each side is presented below.

Left Side

Integrated Drive Generator

As can be seen, the voltage is the same as when simulated by itself, however, in the complete simulation, a block is used to control the time in which the breaker closes, that is why in both voltage and current graphs can be seen that after 300 ms, the breaker closes, and creates that drop, and from that, it begins to stabilize after feeding the corresponding subsystems on this side. It is worth mentioning that the same thing happens for the right side. The voltage is 162.63 V and the current is 900 A.

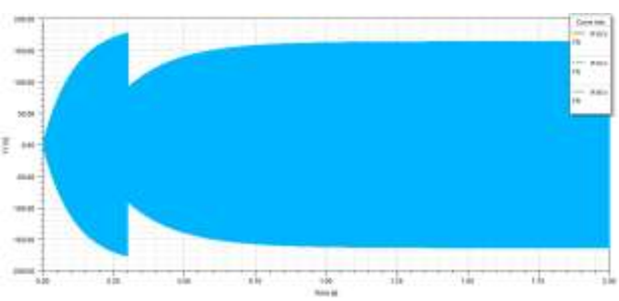

Figure 18 IDG voltage output during a simulation period of 2 seconds

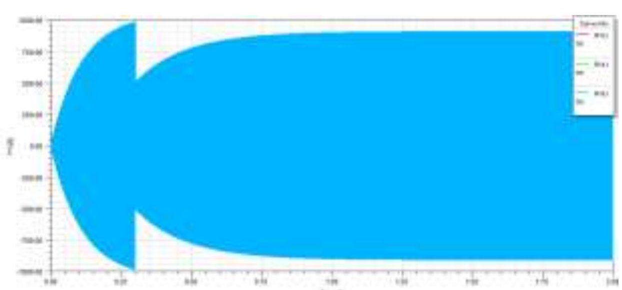

Figure 19 IDG current output during a simulation period of 2 seconds

Transformer Rectifier Unit

Because its main source starts feeding after 0.3 seconds, the TRU outputs are affected by this and as can be seen, after that time, it starts to simulate until it stabilizes after the second, the voltage is still 28 V and a current of approximately 280 A.

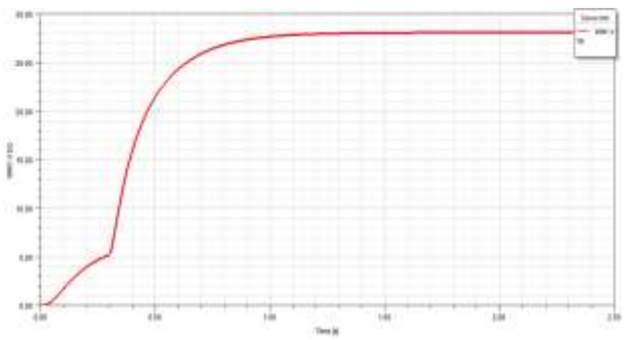

Figure 20 Left side TRU voltage output

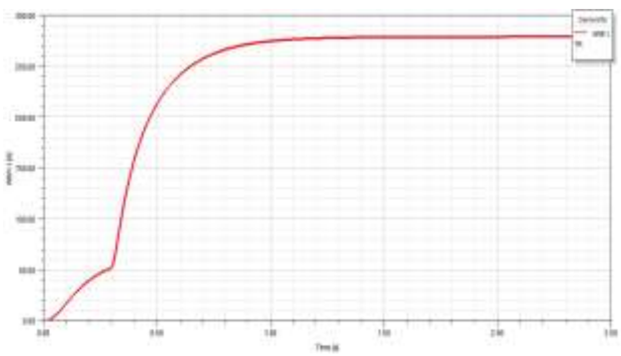

Figure 21 Left side TRU current output

Bars

As seen in the simulation development section, the bars are represented by electrical resistors, and the resulting values will depend on the value of these resistors. For this side, we have: the main AC busbar, the utility busbar, the DC busbar and the Capitan Flight Instrument busbar.

The main AC bus and the utility bus are three-phase AC bus, where their voltage goes into the range of 160 VAC with a current of 520 A.

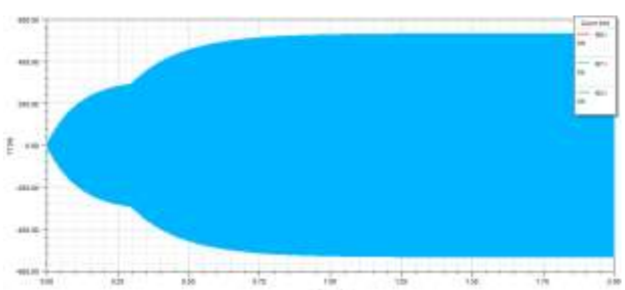

Figure 22 Utility bus current output

The DC bar and the Capitan Flight Instrument bar, are direct current, each will have a voltage of 28 V with current of 28 A when given a unit value to the resistor.

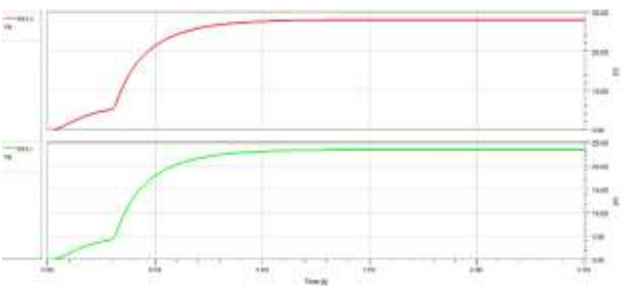

Figure 23 DC bus voltage and current

Flight Control Direct Current (FCDC)

In this section, the output of the electrical resistor representing this subsystem with the three power supplies is going to be presented.

DC Bus

First, we have the corresponding output when the DC bus is feeding this subsystem.

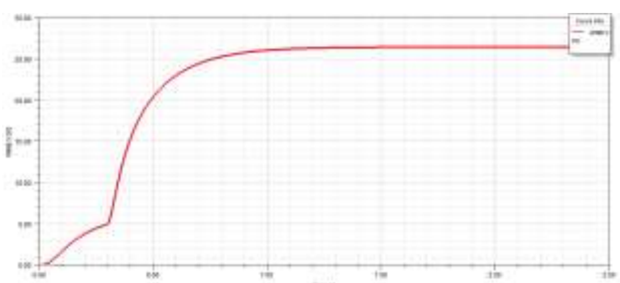

Figure 24 Resulting voltage of FCDC when the DC bus supplies it

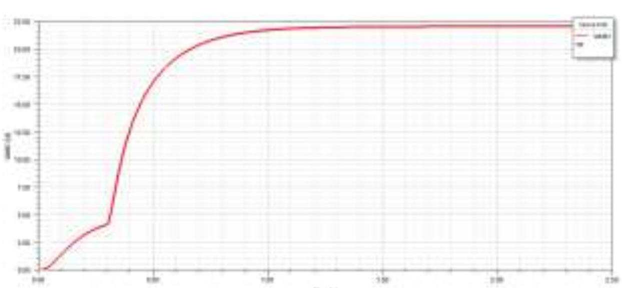

Figure 25 Resulting current of FCDC when the DC bus is feeding it

As can be seen, the voltage is approximately 26.5V with a current of 22.5A.

Battery

For the case when the battery feeds it, if compared with the previous graph, the response to the power supply is direct, with a voltage of 23.75 V and a current of 20 A.

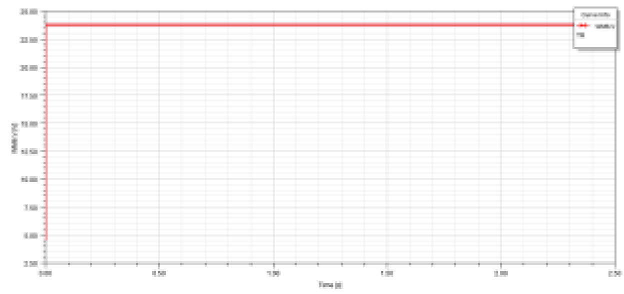

Figure 26 Resulting voltage of FCDC when powered from the battery

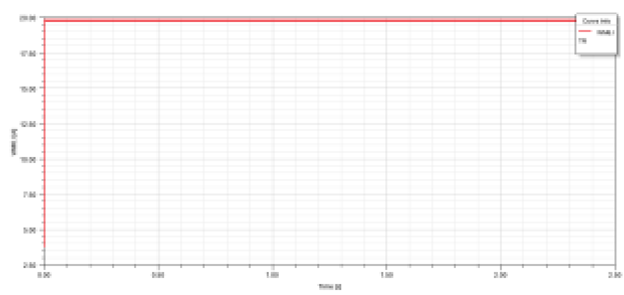

Figure 27 Resulting FCDC current when supplied from the battery

PMG

And finally, when fed from the Permanent Magnet Generator, the voltage is 22.5 V and a current of 18.75 A, and the response also depends on the PMG obtained from the Backup Generator Converter, which is a subsystem that works under abnormal conditions such as emergency, which is capable of feeding either side, however, only the part of the TRU along with the transfer bar and the FCDC delivering a power of 25 kVA with a voltage of 115 VAC three-phase.

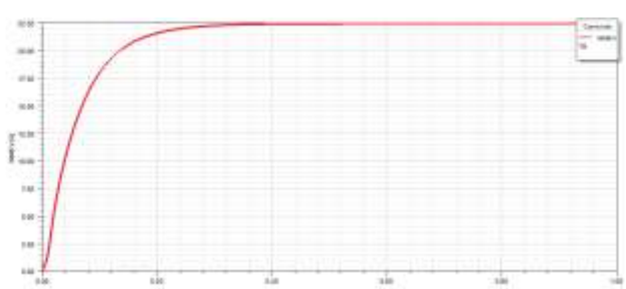

Figure 28 Resulting FCDC voltage when fed through the PMG

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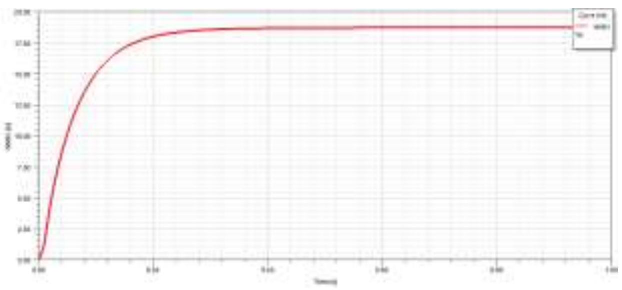

Figure 29 Resulting FCDC current when fed through the PMG

Right side

For this side, the results for the Transformer Rectifier Unit are exactly the same as mentioned above, as well as for the Integrated Drive Generator.

Main Battery / Main Battery Charger

The output of the battery is 23.75 V and the graphs corresponding to the charger are shown below, where, in the same way, after it starts feeding, it stabilizes with a voltage of 24 V and 14.25 kW of power.

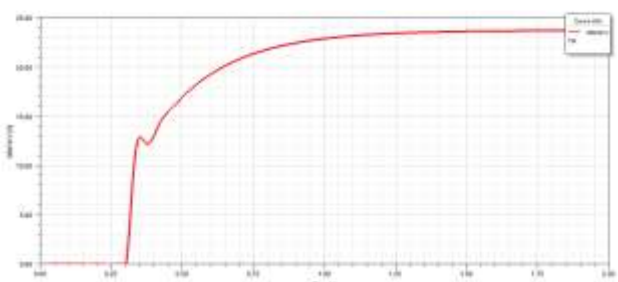

Figure 30 Resulting voltage of the charger

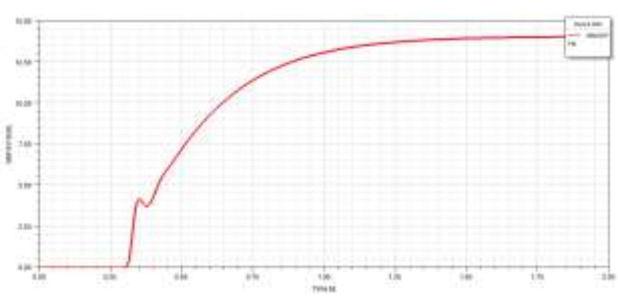

Figure 31 Resulting power of the charger

Bars

On this side, the following busbars are present: the right AC main bus, In Flight Entertainment utility bus and utility bus, IFE SECT 1 bus, as well as the GND SVC ground service bus, the First Official Flight Instrument bus and the right CD bus.

Both the main right AC bus, as well as the utility bus, IFE utility, IFE SECT 1 bus and GND SVC are three-phase alternating current, where the voltage is 162.63 V and the current depends on their values given to the electrical resistors, and ranges between 300 to 400 A.

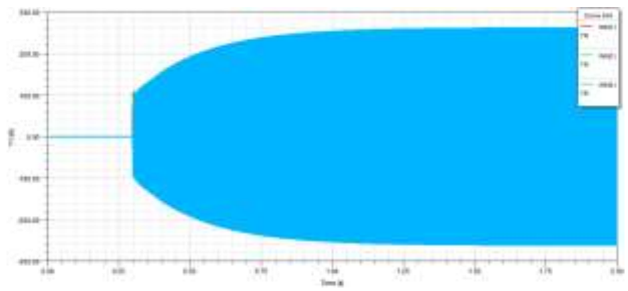

Figure 32 Resulting current of the IFE utility bus

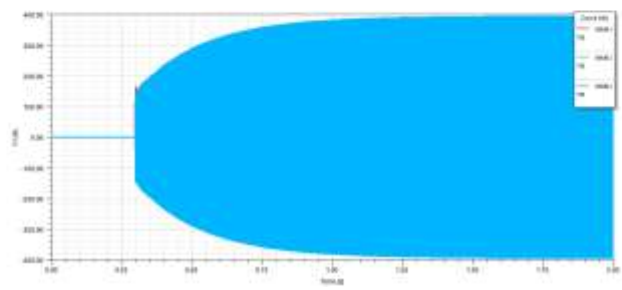

Figure 33 Resulting current of the IFE SECT 1 bus

In the case of the right CD bar and First Official Flight Instrument, they are direct current, with a voltage of 28 V and 28 A.

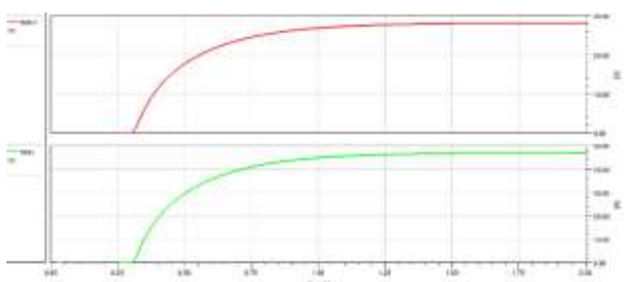

Figure 34 Voltage and current of the right CD busbar

Flight Control Direct Current

On this side, the same happens as on the left side, we have the three possible power supplies, so the results obtained during the simulation for this section are presented below.

Power supplies	Voltage	Corriente
CD Bar	26 V	52 A
Battery	23.75 V	47.5 A
PMG	20 V	40 A

Table 1 FCDC output voltage and current results according to its power supply

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Conclusions

As it could be observed in the results area, it was proved that the subsystems work properly when tested both individually and when joined according to the power flow diagram, and therefore, the results between them are very similar, so it is proved that the simulation works, as it was for the TRU case, and for the case of the IDG, each one, was able to feed its corresponding side, that is to say, contemplating the part of the loads and of what each one of the subsystems consumed, noticing that the right side consumes more than the left one, due to the part that has other busbars, as well as the charger and its corresponding battery.

On the other hand, the values of the busbars can be modified, and the more realistic their values are, the more accurate the results will be to a real aircraft. The present one has switches to control the power supply according to the diagram, and these could be implemented with control so that the change of open and closed is no longer manual and can be changed even when the simulation is running.

The results obtained, help to make a power analysis in each subsystem in order to later implement improvements in its power factor with appropriate circuits.

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